Evolution of European Air Traffic from 2022 Onwards

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Abstract. The war in Ukraine caused by Russian Federation military invasion on February 24, 2022, had a significant impact on configuration of airspace used by civil aviation for global air transportation. Restricted flight regions caused a significant increase in the index of airplane trajectory inefficiency that is a result of airplane trajectory re-planning to avoid entering the risky airspace. Closing full Ukrainian airspace led to the relocation of a portion of Ukrainian cargo and passenger traffic to airports in neighboring countries. Configuration of dangerous airspace directly affected global transportation flows between Europe, North America, and Asian destinations. In this paper, the evolution of air traffic caused by the war in Ukraine has been studied. Statistical analysis of European airport's load is used to get estimation of additional traffic there since 2022. An index of monthly traffic increase is used to calculate traffic fluctuation. Also, statistical analysis of airplane trajectories with high values of trajectory inefficiency index has been used to estimate close airspace influence on particular flight connections.

Keywords: Air navigation · Air traffic · Airport load · Horizontal flight efficiency · Trajectory length · Graph

1 Introduction

The military invasion of Ukraine by the Russian Federation on February 24, 2022, had a dramatic influence on global air transportation system. Full Ukrainian airspace with Kyiv, Lviv, Dnipro, Odesa, and Simferopol's flight information regions has been closed [1, 2]. The use of airspace is limited only to Ukrainian state aircraft and flights under the permission of the general staff of armed forces of Ukraine. It stopped all local commercial air traffic and transit flights through Ukrainian airports. Air Traffic in Ukraine was 1.2% of global traffic before the war. Closed Ukrainian airspace leads to a significant loss of air traffic flows at the global transportation level.

Sanctions and other economic tensions caused limited use of Belorussian and Russian airspaces for most users [3]. Transit air traffic for deals of the airline industry through these airspaces has been canceled. Most airspace users have to avoid entering airspaces

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of Ukraine, Belarus, and Russian Federation. Configuration of closed airspace is big enough to significantly increase index of trajectory inefficiency for most air connections between Europe, North America, and Asian destinations (Fig. 1) [4, 5].

War in Ukraine 2022 caused huge economic impact [6–8]. The global food delivery chain has been broken due to closed transport flows from Ukraine [9]. Many Ukrainian airports have been damaged including many air navigation equipment required to ensure the safety of civil aviation. Dramatic influence led to bankruptcy of many airlines hosted in Ukraine, because of frozen airplanes in Ukrainian airports. Overcoming periods of aviation equipment maintenance will cause serious problems in further system exploitation [10].

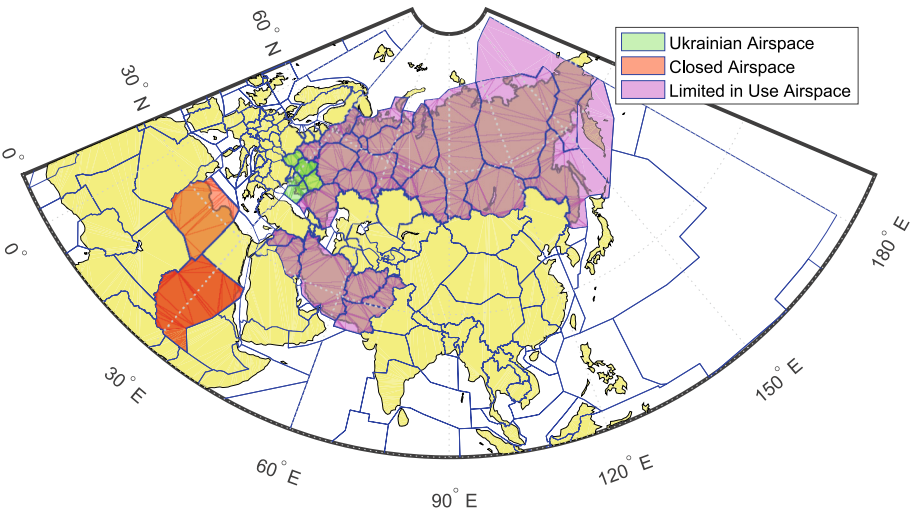

Fig. 1. Configuration of closed and limited in use airspaces.

Configuration of closed airspace is highly not welcome due to the long length spread which is placed between 22.1° and − 168.9° meridians. Also, a configuration of closed airspace is placed in different weather formation regions which significantly affects efficient trajectory planning. Forecasted weather data are used during trajectory planning for upcoming flights to have additional speed input from the tailwind.

Global trends in air transportation systems indicate fast recovery of air traffic after Covid-19 pandemic in the globe and European region, as well [11]. During full 2023 air traffic reached 10 M flights in ECAC (European Civil Aviation Conference) airspace which increased in 9.8% in comparison with the previous year. However still 8.5% below the pre-pandemic level (11.1 M) [12].

Trajectory data of each airspace user is currently available by Automatic Dependent Surveilance-Broadcust (ADS-B) [13]. A lot of commercially available databases form a large archive of precise airplane trajectories available by flight number and date of realization [14, 15]. Big data analysis of statistical realization of each flight makes it possible to get precise parameter measurements. ADS-B data sets are widely used for

flight phase identification [16], analysis of delays in air traffic, and study of air navigation resistance to jamming actions [17]. Also, ADS-B data is used in trajectory analysis to identify weather influence on effective lateral trajectory selection [18].

In the paper, an air traffic redistribution in Europe caused by the war in Ukraine has been analyzed. An airport's daily traffic data has been used for statistical analysis of changes in the air transportation system. Also, trajectory data of historical flights has been used to study influence of closed airspace on trajectory variation of particular flight connections.

2 Growing Airports Load in Neighboring Countries

Ukraine is one of the biggest European countries with an area of about 0.6 M km^2 and a population 36.7 M people (42 M people before the war). Ukrainian air transportation network in 2021 included 27 certified airports, 18 of them has international checkpoints [19]. Statistics of load for the biggest Ukrainian airport "Boryspil" (UKBB) in daily and monthly total number of flights for the period before the war are shown in Fig. 2.

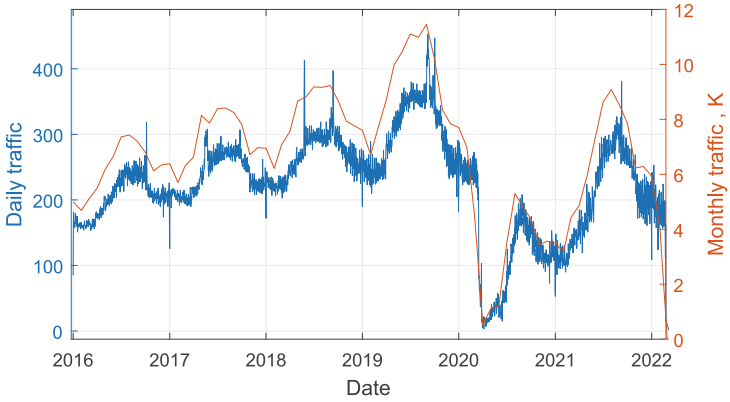

Fig. 2. Total number of flights in UKBB airport.

Season traffic variation in UKBB during pre-Covid period reaches more than 400 flights per day and about 11.2 K per month. Closing Ukrainian airspace on Feb 24, 2022 for a long duration led to moving the biggest part of this traffic to airports in neighbor countries. Redistribution of air traffic in airports close to Ukrainian boundary was a necessary action to meet the demand for cargo transfer to Ukraine and passenger traffic. New traffic chains have been developed with automotive transfer from places in Ukraine to closed airports in Poland, Hungary, and Slovakia to get access to air transportation services.

The raw air traffic data [20] in neighboring countries to Ukraine by each airport separately has been analyzed to measure air traffic redistribution. A season traffic variation during Feb 2021—Feb 2022 has been used to analyze the increase in traffic from Mar 2022—Mar 2024. The total number of flights of the top ten European airports close to

Ukrainian boundaries with increased monthly traffic compared to Feb 2021—Feb 2022 period are shown in Fig. 3.

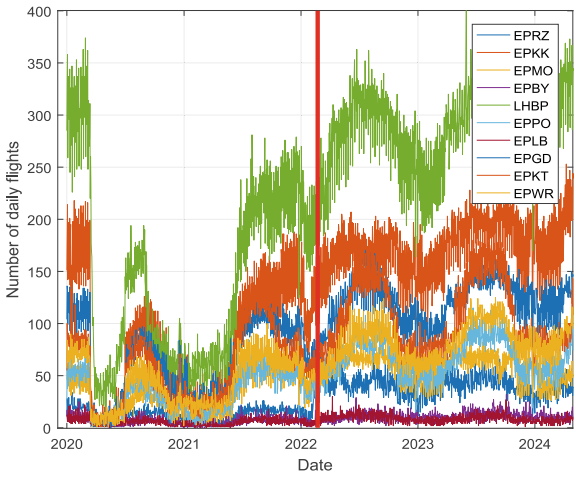

Fig. 3. Number of daily flights in the top ten airports close to Ukraine.

An index of monthly traffic increase (MTI) is used to calculate traffic fluctuation. Total monthly traffic in airport during Feb 2021—Feb 2022 is used as a reference:

$$M_{2021} = \{M_{21Feb}, M_{21Mar}, M_{21Apr}, \ldots, M_{22Jan}\}.$$

Monthly traffic increase estimates are as follows:

$$MTI = mean\left(\frac{C_i - M_{2021}}{M_{2021}}\right), \tag{1}$$

where C is matrix of monthly traffic during considered period; $mean()$ is a mean function; $i = [2022, 2023, 2024]$.

MTI shows a portion of traffic to traffic amount in the reference period. We analyze a historical data set of raw traffic data for 26 international airports in the closest countries to Ukraine in the period 2016–2024 (Poland—15 airports; Turkey—6 airports; Slovakia—1 airport; Hungary—1 airport; Moldova—1 airport; Romania—2 airports). Results of MTI calculation are shown in Table 1 and geometry of considered airports is represented in Fig. 4.

Results of MTI analysis indicate that four airports in Poland are at the top of the table. Airports EPKK and EPMO have at least double increased traffic in comparison to the period before the war. Also, international airport of Budapest (LHBP), Hungary has increased MTI by 1.8 times. However, the highest increase is for Rzeszow—Jasionka Airport (EPRZ) which is 80 km from the administrative boundary of Ukraine. Daily traffic variation for the last 8 years for EPRZ is shown in Fig. 5 and monthly traffic is analyzed in Fig. 6.

Table 1. Results of MTI calculation.

Airport	Mean daily traffic, 2021	Mean daily traffic, 2024	MTI
EPRZ	6.3	11.9	3.9
EPKK	69.7	124.2	2.0
EPMO	90.2	180.0	2.0
EPBY	67.3	113.3	1.8
LHBP	5.4	8.6	1.8

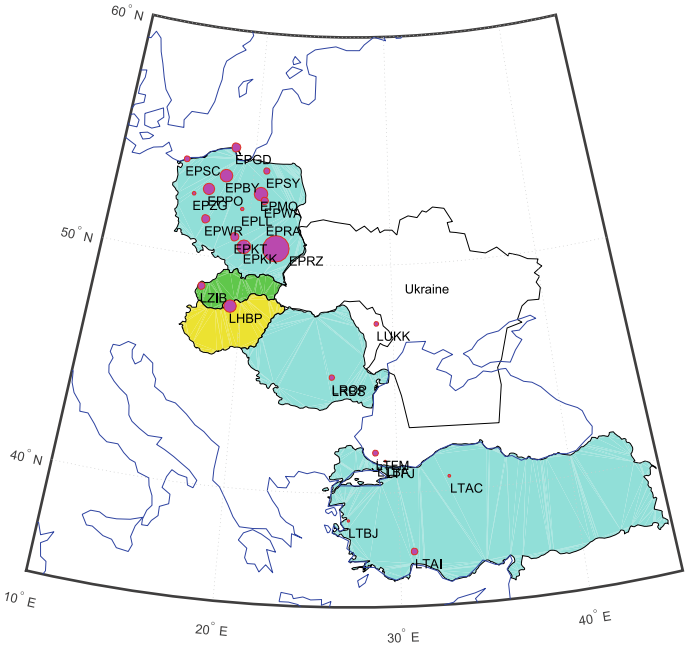

Fig. 4. Configuration of airports with high MTI.

Monthly traffic variation in EPRZ indicates a clear increase in comparison to 2021 which is holding up for two years period 2022–2024. Airport EPRZ is not considered by airlines as a basic facility. Thus, the number of arrivals and departures is almost the same.

3 Air Transportation System of Ukraine

Ukrainian airport network supports both local and international flights. In 2013 air transportation system included 25 international and nine local airports [21]. Configuration of local airport network in 2013 is presented in Fig. 7. Mean weighted centrality of air transportation graph was 12.04 K km.

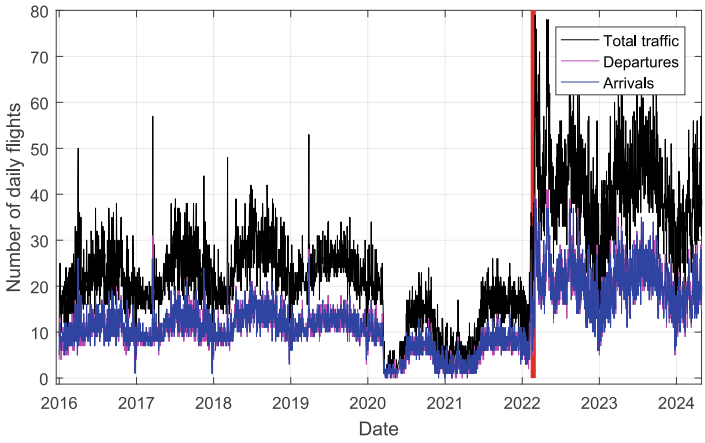

Fig. 5. Daily traffic variation in EPRZ.

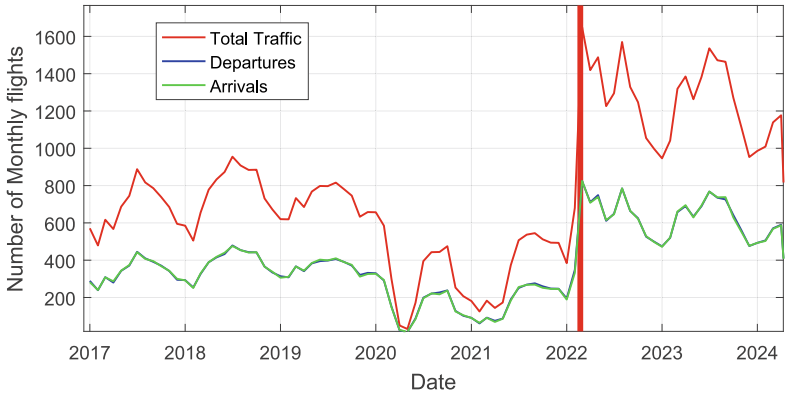

Fig. 6. Monthly traffic variation in EPRZ.

The West-North and East-South parts of the network were well configured to minimize time of users traveling to services of air transport. Most airports are co-located with big cities which is correlated with population distribution. Weighted centrality was in the range of 0.93 K km (UKDR) to 1.81 K km (UKLU).

Due to closed Ukrainian airspace, passenger and cargo transportation chains have been redistributed. We use a numerical method of computation to identify areas close to the airport facility. It makes sense to use the closed airport to get an efficient transportation chain structure. The whole Ukrainian territory was partitioned into a set of elementary squared cells with side length up to 3 km. The length from each cell center to considered airport facility was analyzed. There are four airports that are close: LUKK (effective for 83.4% of Ukrainian territory), EPRZ (14.8%), EPRA (0.93), LROP (0.72). Results of closed areas to airports are shown in Fig. 8.

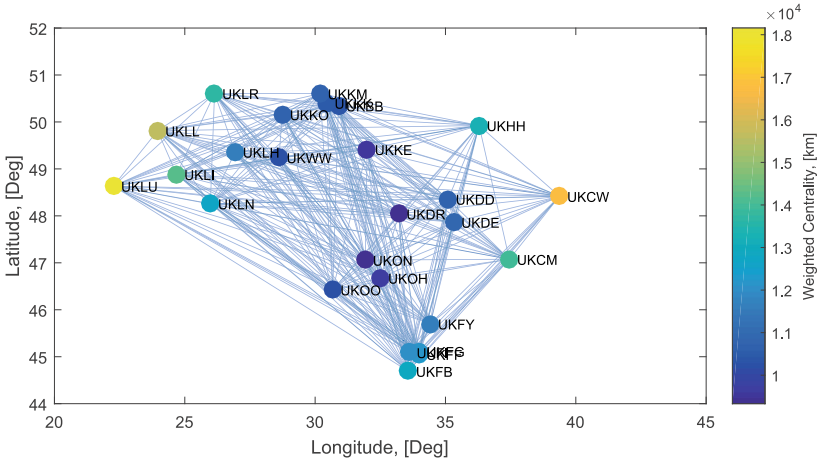

Fig. 7. Configuration of Ukrainian airport network.

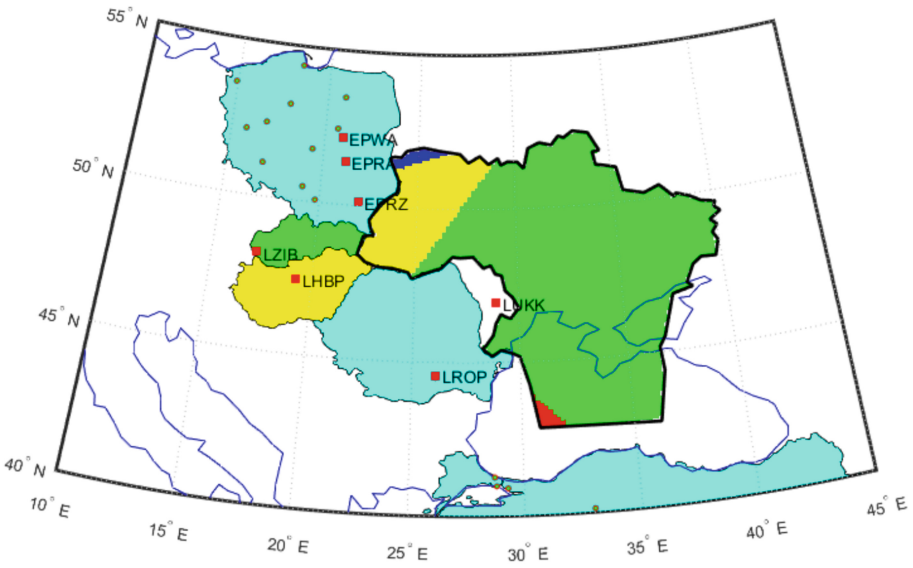

Fig. 8. Closed airport estimation for Ukrainian territory.

The same result has been obtained by calculating an area limited by Voronoi diagram. Due to significant place of LUKK as an option for getting access to air transportation services, the volume of air traffic has not increased significantly for this airport.

4 Horizontal Flight Efficiency

Closed airspace has a significant influence on global transportation air flows. It was a result of avoiding usage of risky airspace for transit air traffic. Geometry of limited airspace significantly increases the index of lateral trajectory inefficiency. Flight connections between European countries and South Korea and Japan are affected the most. Also, Europe-Asia flight flows led to a significant increase in the air traffic flow of Turkey airspace. Operation at a high capacity levels is always connected with risks to flight safety [22, 23].

Let's study an influence of closed airspace on particular flight connection between Warsaw Frederic Chopin (EPWA) and Narita, Tokyo (RJAA) international airports. Flight LOT 79 of Polish Airlines is served by B789 airplane and is mostly in the daily schedule. The direct length between departure and destination airports is about 9.9 K km. Trajectory data of LOT 79 fixed by a network of ground receivers within ADS-B technology has been used in analysis. One-side journey data for the period from Apr 1 to May 25 of 2024 is used. This data includes 48 unique trajectory realizations. We use specially developed software in the Matlab suite to analyze a long archive of trajectory data. Trajectory variation is shown in Fig. 9. Also, Fig. 9 shows a great circle line and airplane trajectory before the war period, when actual closed airspace was opened to use. The great circle line is the shortest path on the spherical model which is used in for horizontal flight efficiency calculation. However great circle line does not take into account current weather distribution.

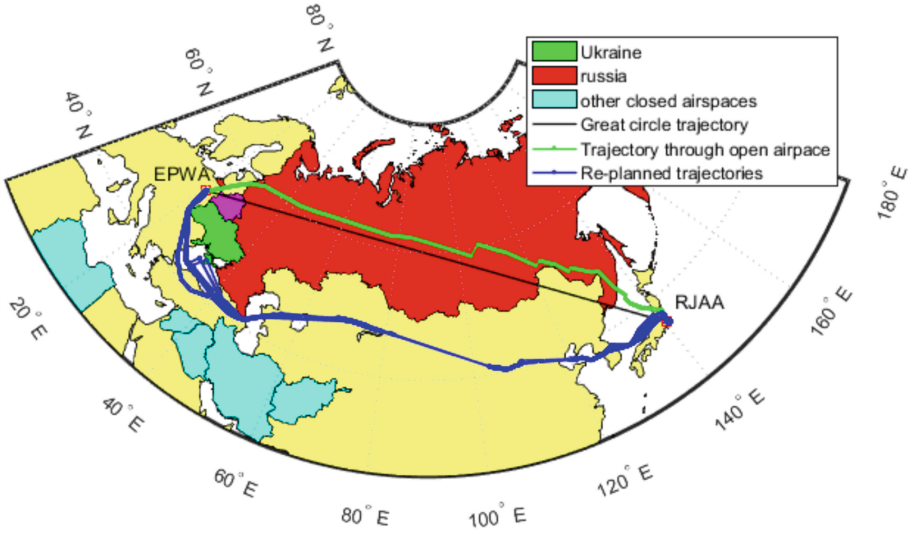

Fig. 9. Trajectory variation of LOT79 during April-May 2024.

Local weather configuration variates actual airplane trajectory to make maximum wind input in effective trajectory formation.

Raw trajectory data has been used to estimate a total trajectory length. Total trajectory length is calculated as a sum of arch length of each leg in trajectory. Histograms of flight trajectory variation and total time of flight variation are shown in Figs. 10 and 11.

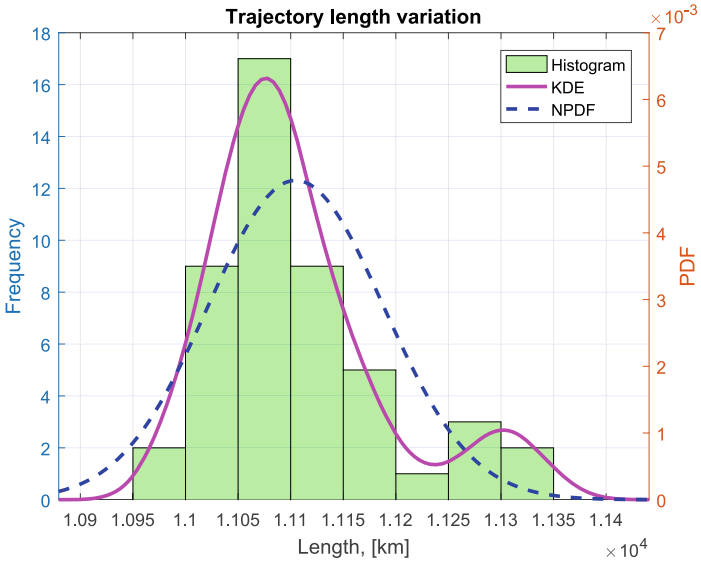

Fig. 10. Trajectory length variation for LOT 79.

Comparison of trajectory configuration before and after the airspace has been restricted could indicate a dramatical impact.

Trajectory length has increased by 1.8 K km (Mean trajectory length was 9.3 K km before the war and is 11.1 K km after). Duration of flight connection increased for 21 min only (before is 11:49, after is 12:10). Small impact in flight duration is a result of effective trajectory selection based on wind distribution and optimal speed control during the flight.

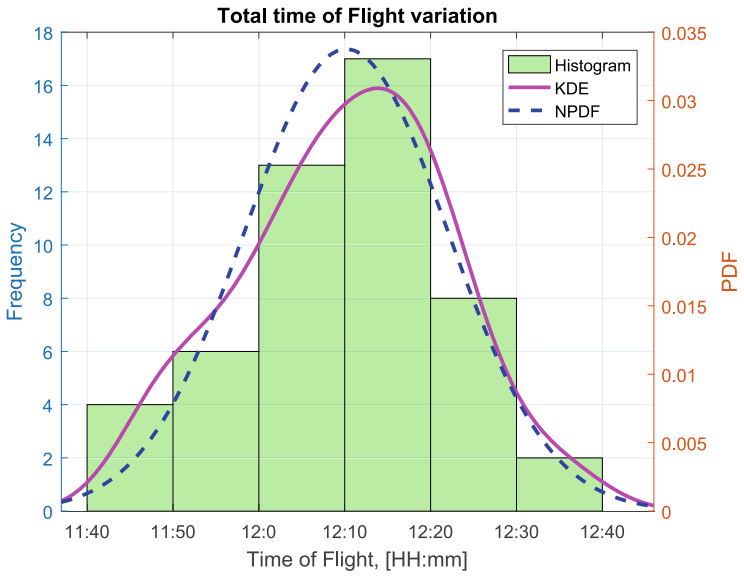

Fig. 11. Variation of flight duration for LOT 79.

5 Conclusions

The closing of Ukrainian airspace on Feb 24, 2022, because of the military invasion of Russian Federation had a dramatic influence on civil aviation. Access to air transportation services has been provided via airports of neighboring countries close to Ukrainian administrative boundaries. Presented in the paper results of statistical analysis in airport demand show a constant increase in traffic of four airports in Poland and Budapest airport in Hungary. Part of air traffic is related To/From Ukraine. The airport of Rzeszow (Poland) which is 80 km from Ukraine increased its load by nearly four times. Proposed index of monthly traffic increase could be a good measure for air traffic analysis.

Results of statistical analysis for the Warsaw—Tokyo flight connection show a significant increase in total trajectory length. The mean value for total trajectory length reaches an extra 1.8 K km required to avoid entering the risky airspace.

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